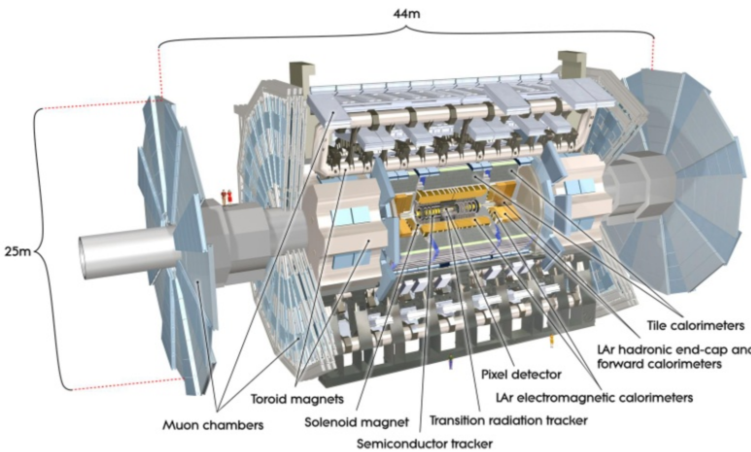
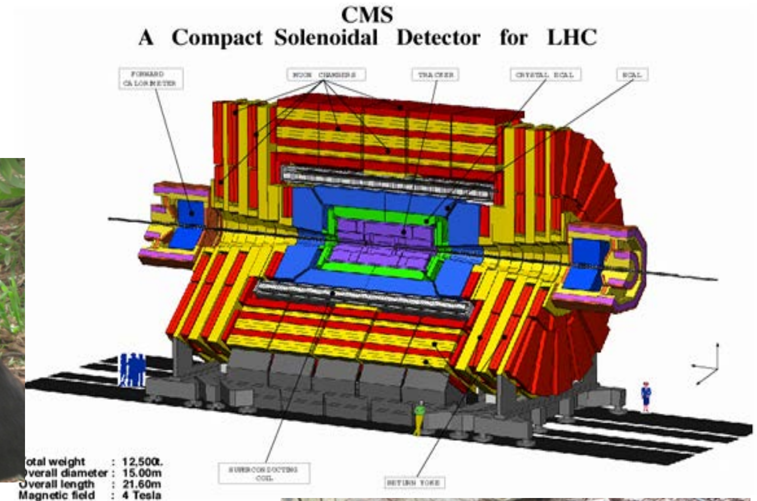
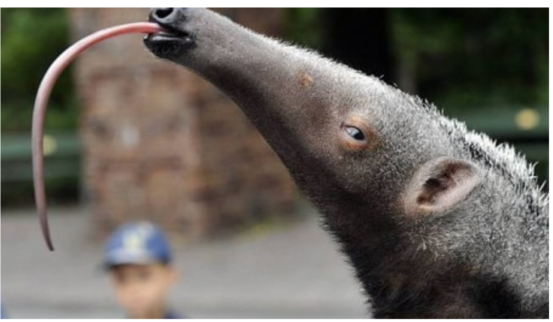
The Zoo of BSM Physics at the LHC







8/1/12
T.G. Rizzo

This is a meta-talk about particle phenomenology

Outline

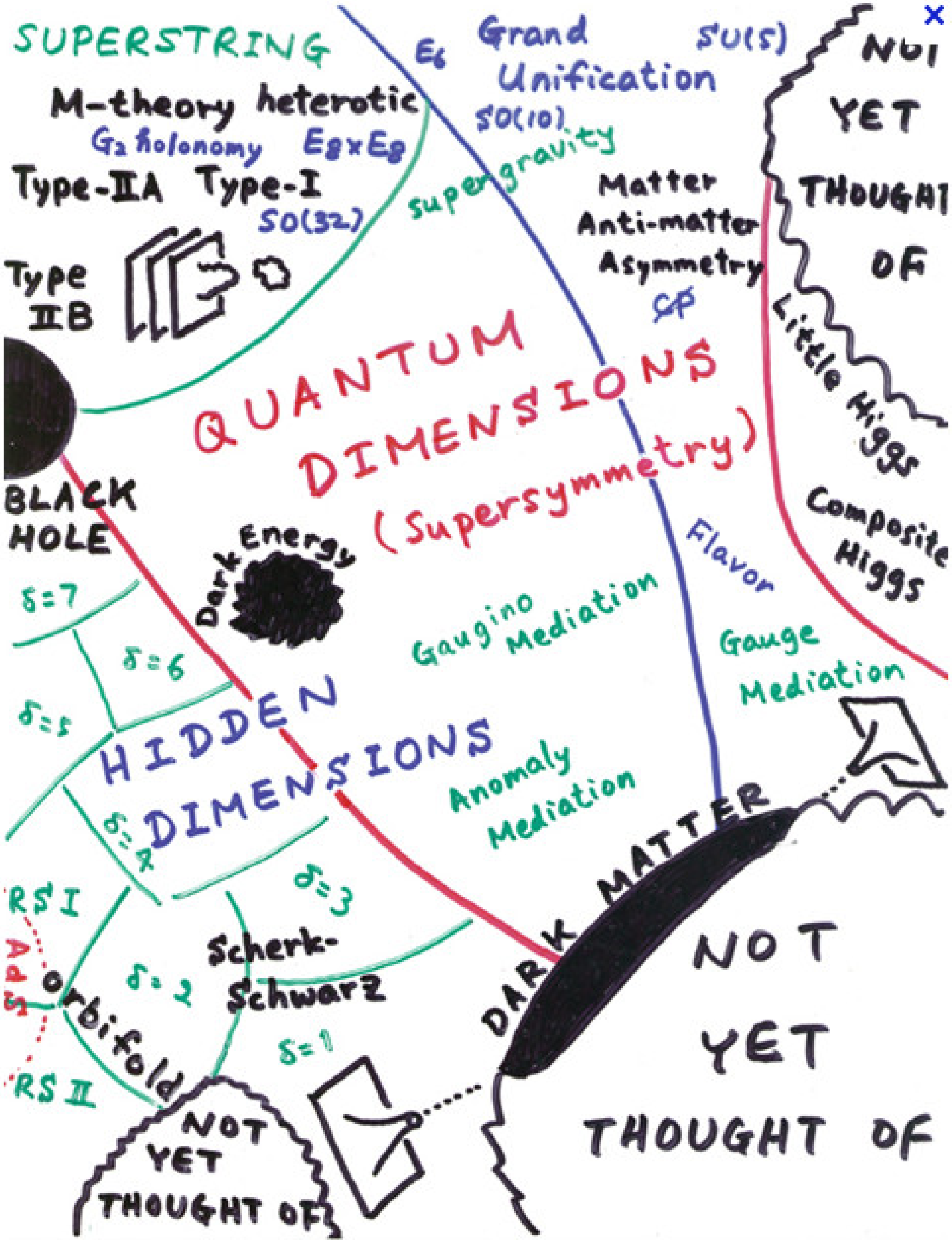
- What is the BSM Zoo ??
- Questions for the Zoo about LHC signals
- What's in the Zoo?
- The Nature of the Zoo & Adding Specimens
- An Example Case
- Conclusions

What is the BSM 'Zoo' ??

When one talks about searches and discoveries at the LHC the subjects are usually 'the Higgs' or, in the case of BSM physics, 'supersymmetry' , 'extra dimensions' or even 'the 4th generation'.

While these are certainly the most popular targets for LHC searches for many good reasons, there are very many other more unconventional & exotic possibilities for new physics discoveries …some of which we haven't thought of yet!

This is the Zoo.. the set of all BSM theoretical ideas & models.. some of which are very unusual & exotic 'animals' but others are as familiar as your family's cat



H. Murayama

Many of these models of new BSM physics were proposed to address some of the questions that are left unanswered by the SM :

E.g. ,the gauge hierarchy problem or the generation & flavor problems

..or simply to explain any data not consistent w/ the SM such as the top FB asymmetry, a too large rate for $h \to \gamma\gamma$ or a 130 GeV 'DM' γ-line

As Hitoshi emphasized, the Zoo is a mixture of both known & unknown beasts resulting from BSM physics. Of course, the definition of ‘unknown’ is time-dependent as we continue to discover new ideas…the Romans did not know about Tasmanian Devils & we didn’t know about extra dimensions phenomenology in 1997.

(How would their signature have been interpreted if they had been seen at the SSC before the theory existed?)

This leads us to raise a number of important issues & ask some related questions

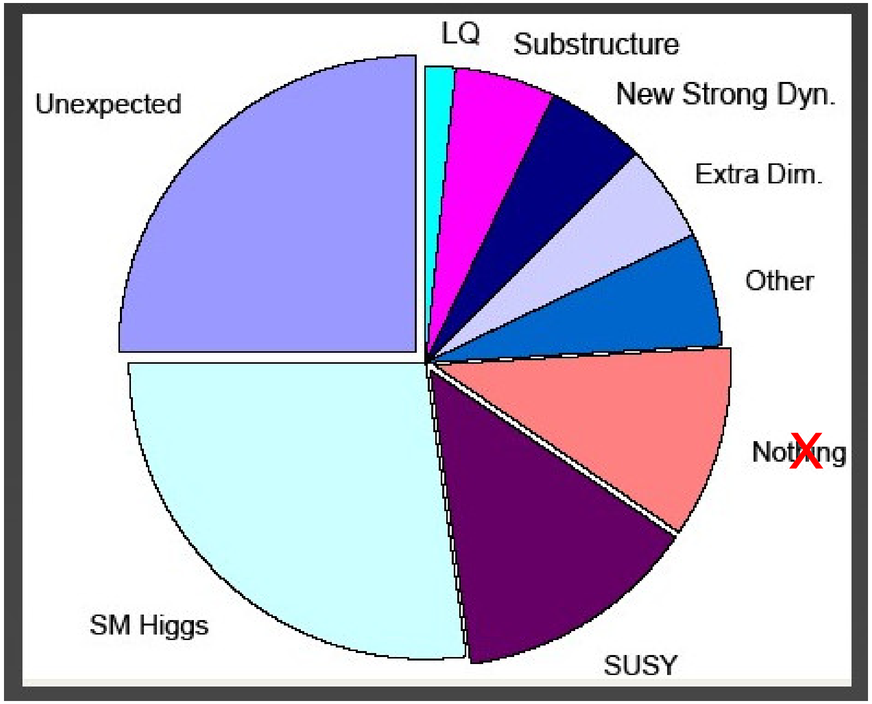
Outside of the scenarios that we have already constructed we don’t know if arbitrary new physics at the TeV scale would necessarily lead to observable signals at the LHC (that will be recognized as such)

The LHC is a machine of exploration….

- When exploring the unknown, it is often true that what one finds is not always the thing you were originally looking for… can the LHC only find the things we already know about ?

A well-known example…

From Jan 2009 poll

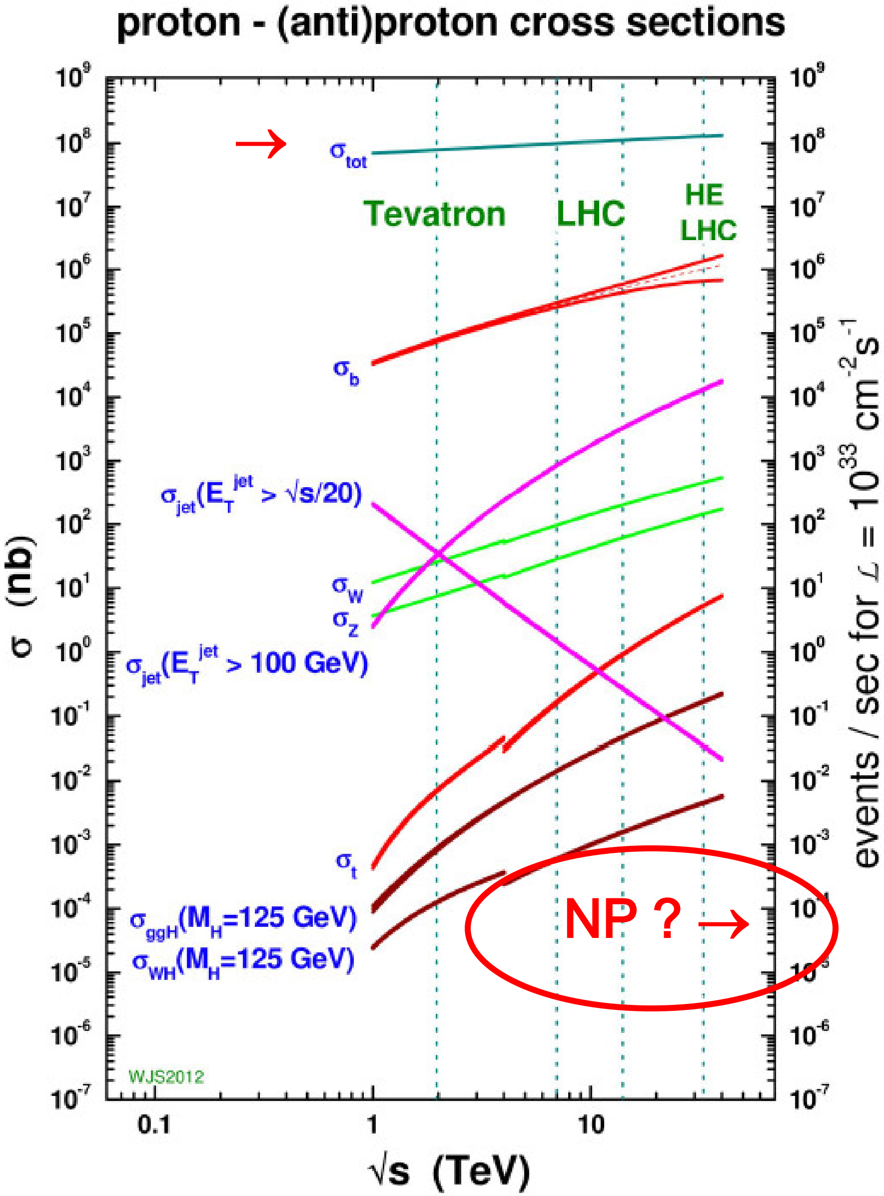


- Remember: in the past, sometimes the greatest discovery made at an accelerator was for something unexpected at the time of its proposal or construction, e.g., the J/ψ, charm & τ at SPEAR or even quarks themselves nearby

- The hope is that examining the signals within enough NP scenarios (known unknowns) would then 'train' us to find the real NP no matter what it may be (unknown unknowns)

→ Examining the Zoo as a whole sometimes let's us think outside of any specific model context & to ask questions that we don't usually think too much about (but perhaps should)

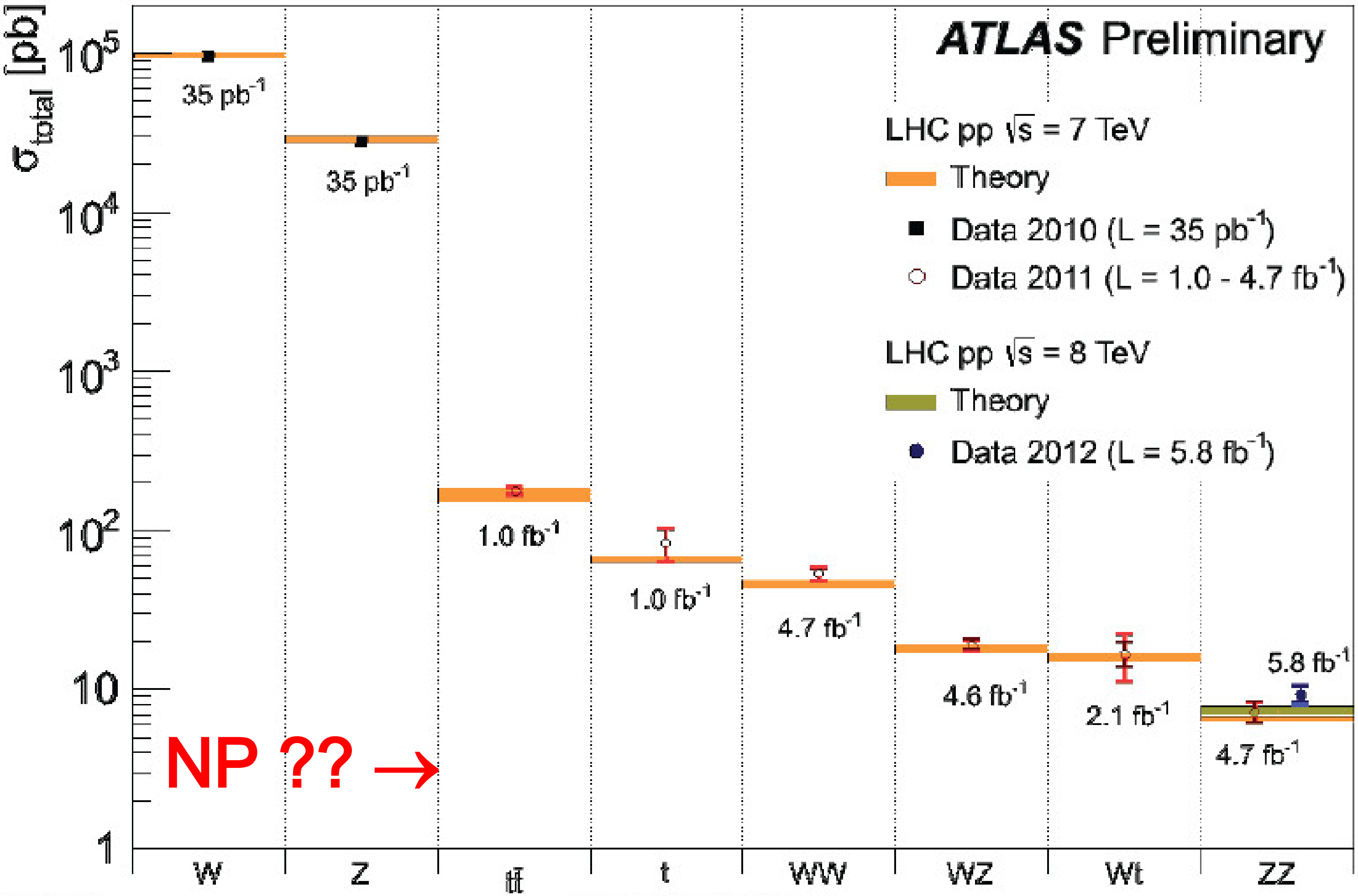
Could New Physics Be Missed at the LHC ??



- assuming NP is accessible kinematically at the LHC will it always be observable if the signal rate is large enough?
- Note almost all interactions at the LHC are 'non-interesting' soft QCD processes which don't probe any NP (as far as we know)
- These correspond to gigantic event rates… beyond our capability to record

Summary of Standard Model measurements

- Foundations for searches - measurements of W, Z, diboson and top prod^n:



- The LHC experiments only ‘write events to tape’ at the rate of a ~few hundred Hz but pp collision events occur much faster than this ~100 MHz !

Lowest un-prescaled thresholds (examples)

Item	p_T threshold (GeV)	Rate (Hz) 5×10^{33}
Incl. e	24	70
Incl. μ	24	45
ee	12	8
μμ	13	5
ττ	29,20	12
γγ	35,25	10
E_T^{miss}	80	17
5j	55	8

Managed to keep inclusive un-prescaled lepton thresholds within ~ 5 GeV over last two years in spite factor ~ 70 peak lumi increase

High-Level Trigger @ 6e33

(Unprescaled) Object	Trigger Threshold (GeV)	Rate (Hz)	Physics
Single Muon	40	21	Searches
Single Isolated muon	24	43	Standard Model
Double muon	(17, 8) [13, 8 for parked data]	20 [30]	Standard Model / Higgs
Single Electron	80	8	Searches
Single Isolated Electron	27	59	Standard Model
Double Electron	(17, 8)	8	Standard Model / Higgs
Single Photon	150	5	Searches
Double Photon	(36, 22)	7	Higgs
Muon + Ele x-trigger	(17, 8), (5, 5, 8), (8, 8, 8)	3	Standard Model / Higgs
Single PFJet	320	9	Standard Model
QuadJet	80 [50 for parked data]	8[100]	Standard Model /Searches
Six Jet	(6 x 45), (4 x 60, 2 x 20)	3	Searches
MET	120	4	Searches
HT	750	6	Searches

Chris Tully

- ATLAS & CMS require some ‘hard’ physics, e.g., jets, leptons, MET, etc, (or combos) above some energy threshold to trigger the recording of an event.

- Something to think about: as long as the NP passes at least one trigger it will be found if S/B (and √S/B) is suitably large. But could there be some weird NP that is more subtle & fails all the usual triggers???

- Issue becomes more serious as trigger thresholds are raised due to, e.g., the increasing pile-up

→ An advantage of $e^+ e^-$ colliders

ATLAS

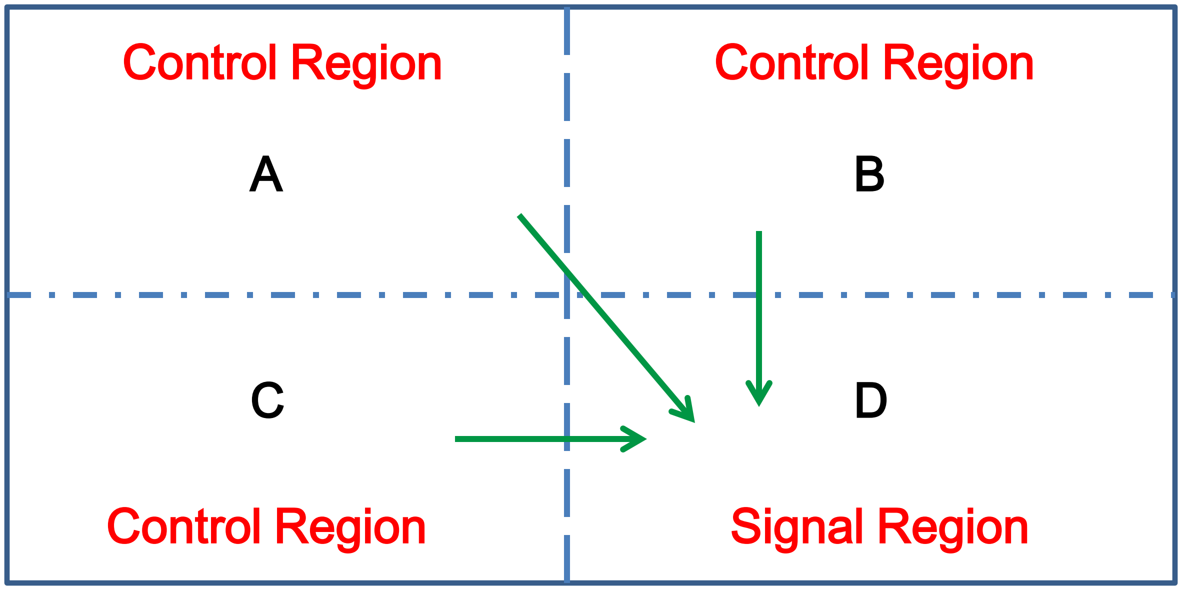
Can NP be hiding in 'the backgrounds' ?

It goes without saying that if you want to do a search for BSM physics you need to understand the SM backgrounds as well as the limitations of your experimental set up.

Seeing a photon line or annular modulation were characterized as 'background free' signals for DM observation until both were observed at several σ. Now many believe these are possibly unknown systematic/detector effects (the jury is still out).

Backgrounds are usually determined by some combination of direct calculation and employing 'control regions' that are thought to be signal-free . But what if they aren't?

Conventional non-Resonant NP Search



Measure the 'SM backgrounds' in control regions (where no NP is expected..but can we be sure?) & then extrapolate to the signal region.. check w/ SM MC & assign a systematic error.

Having excellent control over SM rates in all regions is critical in case of NP 'contamination'… (N)NLO calculations vital !

- What does the Zoo look like? How is it arranged?

- All BSM scenarios can be organized in either a top-down or bottom-up fashion.

- Top-down scenarios provide a general framework/paradigm for a large set of related theoretical ideas . However, the overall structure may not always be designed to address any set of specific experimental or theoretical issues

  SUSY & Extra Dimensions are the best known examples

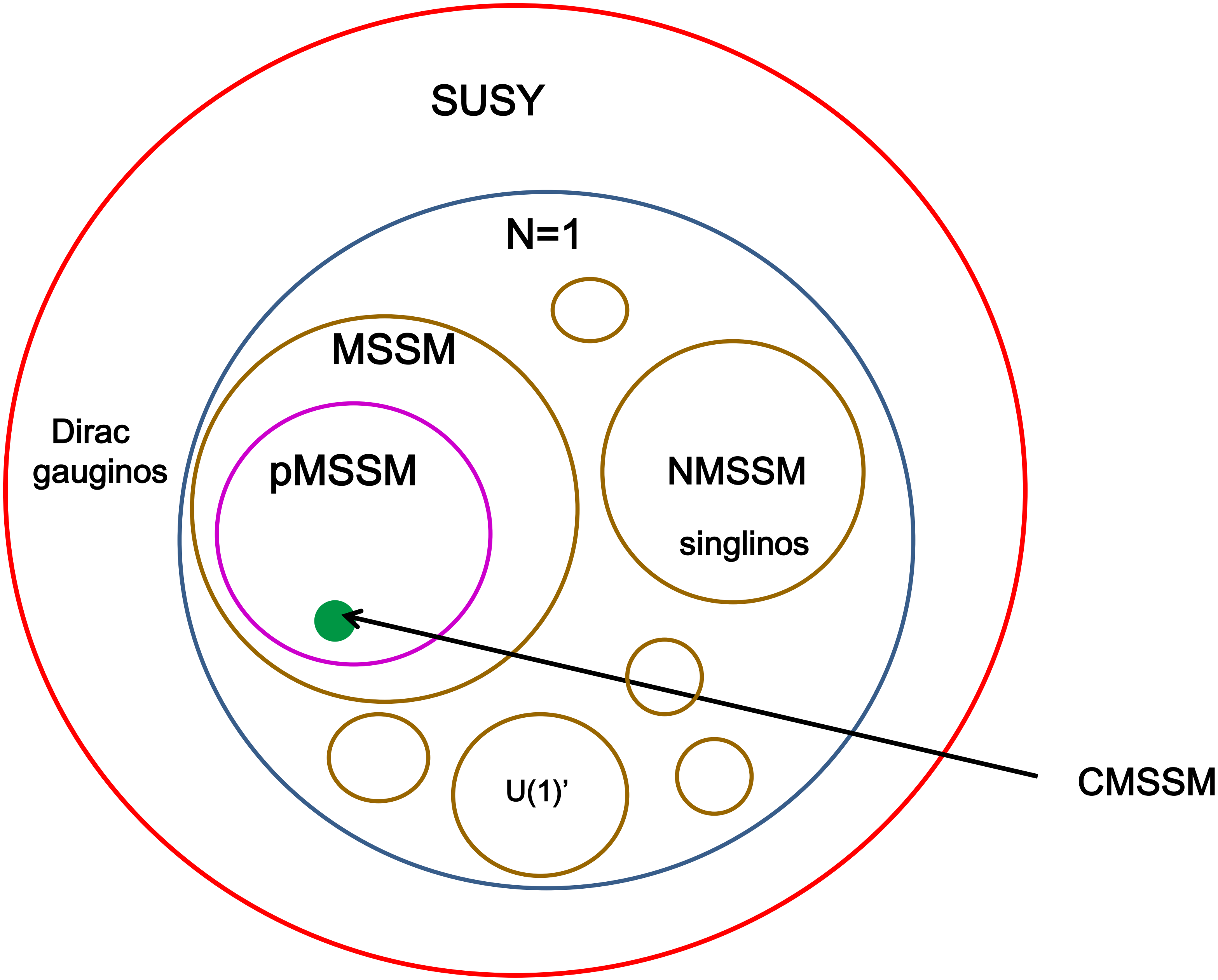
  SUSY was not designed to address the hierarchy problem, produce unification or to give us a DM candidate..these are bonus features! But these are the reasons we are interested in it at the TeV scale today.

• This is NOT the case with Extra Dimensions which were designed to address the hierarchy problem by effectively lowering of the Planck scale to the ~TeV range

• SUSY & ED both represent large families of different models which can have a wide variety of specific predictions but share common elements, e.g., the existence of SUSY partners or the Kaluza-Klein excitations of known particles.. but each is MORE than a collection of models

This is why killing the 4 parameter CMSSM at the LHC is not the same thing as killing SUSY or (even the MSSM)

However, (the proof of) the lack of any SUSY partners at the TeV scale would destroy our main motivation for studying SUSY


SUSY
N=1
MSSM
Dirac
gauginos
pMSSM
NMSSM
singlinos
U(1)’
CMSSM

- Inventing new models within an already existing framework such as SUSY has both advantages & disadvantages

  The overall structure is well-defined & has a number of welcome features BUT you are simultaneously constrained by the overall framework..you can't just do 'anything' you want as there are 'rules' dictated by that specific framework

- This is an advantage in a bottom-up approach which can be a stand-alone model which has been designed only to address a specific issue such as the 'large rate' for $h \to \gamma\gamma$ at the LHC. Here there is a lot more freedom.

  However sometimes bottom-up models are considered 'ugly' as they usually have only a 'single-purpose' use & not part of a larger framework

- Thus the Zoo consists of both models within large top-down frameworks (e.g., the MSSM + new vector-like fields to explain a large $h \to \gamma\gamma$ rate) as well as a huge set of bottom-up 'loners' (e.g., t-channel exchange of a FC Z' to explain the FB top asymmetry at the Tevatron).

How do we 'interact' with the Zoo?

$\rightarrow$ What do BSM phenomenologists DO when we hear (rumors) about a possible new signal for BSM physics??

Panic !

~~Panic !~~

How to ~~Chase Ambulances~~ Build a BSM Model
in Response to New Experimental Results

- Is the experimental result believable/interesting enough to spend some time on? This is a judgment call…

- Is the result already consistent with an existing BSM model ?

- If so, we've found supporting evidence for a known idea
- If not, can we modify an existing scenario to accommodate the new result OR do we need to build something 'entirely new' ? [Recall ED @ the SSC!]

Clearly it is generally far easier to modify a known BSM model than it is to construct something brand new.

Of course we'd have to know WHICH model(s) to start with and this choice need not be unique as there can be multiple ways to explain new data (at least initially)

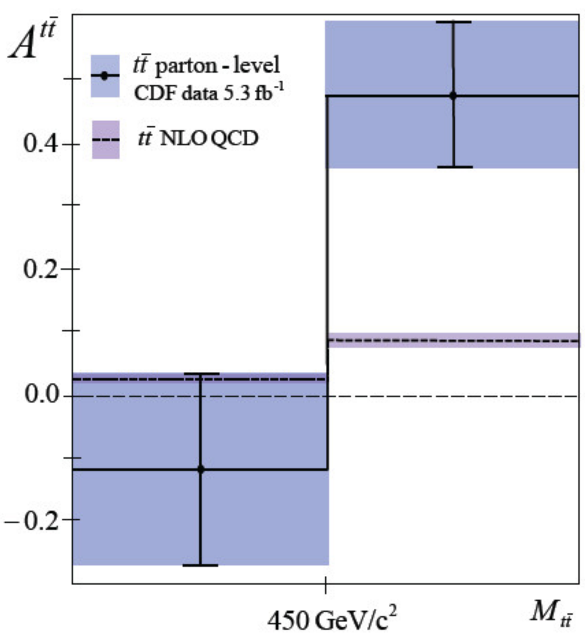
Let's see how this works by considering an example (& learn some physics along the way)

Fermilab-Pub-10-525-E

Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production

We present a new measurement of the inclusive forward-backward $t\bar{t}$ production asymmetry and its rapidity and mass dependence. The measurements are performed with data corresponding to an integrated luminosity of 5.3 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, recorded with the CDF II Detector at the Fermilab Tevatron. Significant inclusive asymmetries are observed in both the laboratory frame and the $t\bar{t}$ rest frame, and in both cases are found to be consistent with CP conservation under interchange of t and $\bar{t}$. In the $t\bar{t}$ rest frame, the asymmetry is observed to increase with the $t\bar{t}$ rapidity difference, Δy, and with the invariant mass $M_{t\bar{t}}$ of the $t\bar{t}$ system. Fully corrected parton-level asymmetries are derived in two regions of each variable, and the asymmetry is found to be most significant at large Δy and $M_{t\bar{t}}$. For $M_{t\bar{t}} \geq 450$ GeV/c^2, the parton-level asymmetry in the $t\bar{t}$ rest frame is $A^{t\bar{t}} = 0.475 \pm 0.114$ compared to a next-to-leading order QCD prediction of 0.088 ± 0.013.

1101.0034



- CDF sees a large FB-asymmetry in top quark pair production at the Tevatron at large invariant masses 3+ σ larger than the NLO prediction

[$q\bar{q}$(~85%)/gg(~15%) $\rightarrow t\bar{t}$]

But $\sigma \sim \sigma_{SM}$ without much room !

- We need a model that modifies the high mass top pair production σ (from qq-bar) in a parity violating way but doesn't much influence the total rate (which is threshold dominated) or the tt-bar invariant mass distribution below ~800 GeV measured at the Tevatron. (No real LHC data then… but now…)

- We could (i) change the t-quark coupling to g's or add new exchanges in either (ii) the s- or (iii) t-channels but (i) is a particularly nasty choice so (ii) or (iii) are options.

- We chose (ii). The new object needs to be a spin-1, color octet to interfere w/ gluon exchange (so that it can be heavy & not distort the cross section too much) but with axial couplings. This beast exists (!): an axigluon from chiral color

The Chiral Color Model

$SU(3)_L \times SU(3)_R \xrightarrow[\langle V \rangle]{} SU(3)_c$ i.e., QCD

Frampton & Glashow '87

$g_L = g_R$

Q_L : (3,0) Q_R : (0,3)

The $G_{L,R}$ gauge bosons mix into the mass eigenstates of gluons & axigluons

Gluons are massless but axigluons gave mass ~g_s V with V ~ TeVs

Here you see an important fact: it is critical for you and/or your co-authors (preferably BOTH) to know what's living in the Zoo already, i.e., to know the literature of existing BSM models so you have a starting point

We could have chosen (iii), i.e., W' & Z' exchange in the t-channel with appropriately chosen couplings to q's & this was done in various forms by other authors..more later

- To proceed further, we need to calculate the axigluon's contribution to the differential cross section for the top quark pair production process

$$\frac{d\hat{\sigma}^{q\bar{q}\to t\bar{t}}}{d\cos\theta^*} = \alpha_s^2 \frac{\pi\sqrt{1-4m^2}}{9\hat{s}}\left[\left(1+4m^2+c^2\right)\left(1-\frac{2g_V^q g_V^t \hat{s}(M_{G'}^2-\hat{s})}{(\hat{s}-M_{G'}^2)^2+M_{G'}^2\Gamma_G^2}+\frac{g_V^{t\,2}(g_V^{q\,2}+g_A^{q\,2})\hat{s}^2}{(\hat{s}-M_{G'}^2)^2+M_{G'}^2\Gamma_G^2}\right)\right.$$
$$+\left(1-4m^2+c^2\right) g_A^{t\,2}(g_V^{q\,2}+g_A^{q\,2})\frac{\hat{s}^2}{(\hat{s}-M_{G'}^2)^2+M_{G'}^2\Gamma_G^2}$$
$$\left.-4g_A^q g_A^t c\left(\frac{\hat{s}(M_{G'}^2-\hat{s})}{(\hat{s}-M_{G'}^2)^2+M_{G'}^2\Gamma_G^2}-2g_V^q g_V^t\frac{\hat{s}^2}{(\hat{s}-M_{G'}^2)^2+M_{G'}^2\Gamma_G^2}\right)\right] \quad (1)$$

where $m^2 = m_t^2/\hat{s}$, $c = \sqrt{1-4m^2}\cos\theta^*$, and θ^* is the angle between the top quark and the incoming quark in the center of mass frame. The forward-backward asymmetry arises solely from the last line in this equation, so to obtain a positive asymmetry we must have $g_A^q g_A^t < 0$

Problem: the axigluon in the literature has $g_V^{t,q} = 0$ (so the interference term does not contribute to σ, that's good) but has $g_A^{t,q} = 1$ which gives the *wrong* sign !

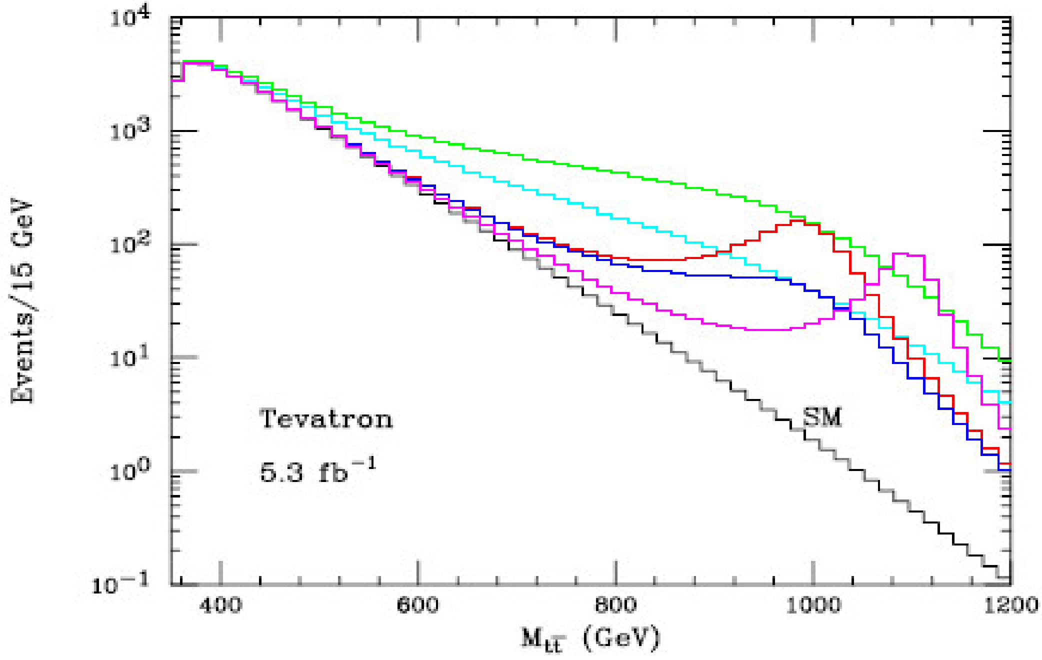
We need to do some 'genetic engineering' to get the right animal

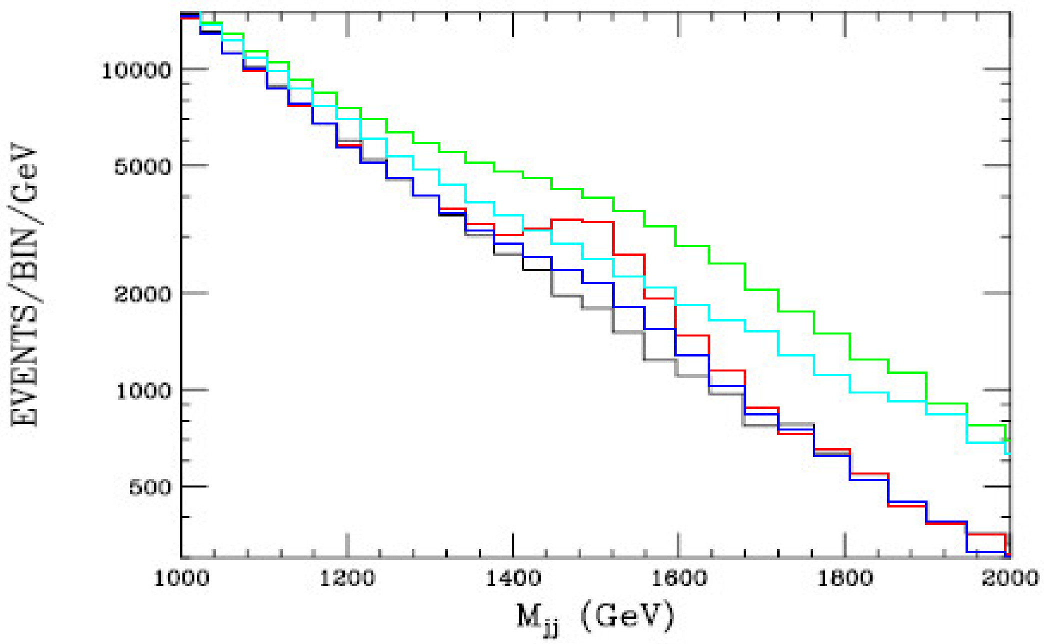
Modified Chiral Color Model

$SU(3)_1 \times SU(3)_2 \rightarrow SU(3)_c$ i.e., QCD

$g_1 \neq g_2$

- Choose how the various q's transform under both $SU(3)_{1,2}$ to get the coupling structure we want & modify the particle content ✓
- Of course there are other worries: we can choose the mass of the axigluon to avoid tt-bar cross section constraints However, since the axigluon couples strongly to light q's, and IF axigluons are relatively narrow, $\Gamma/m < \sim 0.1$, they will appear as resonances in the dijet spectrum


Events/15 GeV
Tevatron
5.3 fb^{-1}
SM
$M_{t\bar{t}}$ (GeV)


EVENTS/BIN/GeV
M_{jj} (GeV)

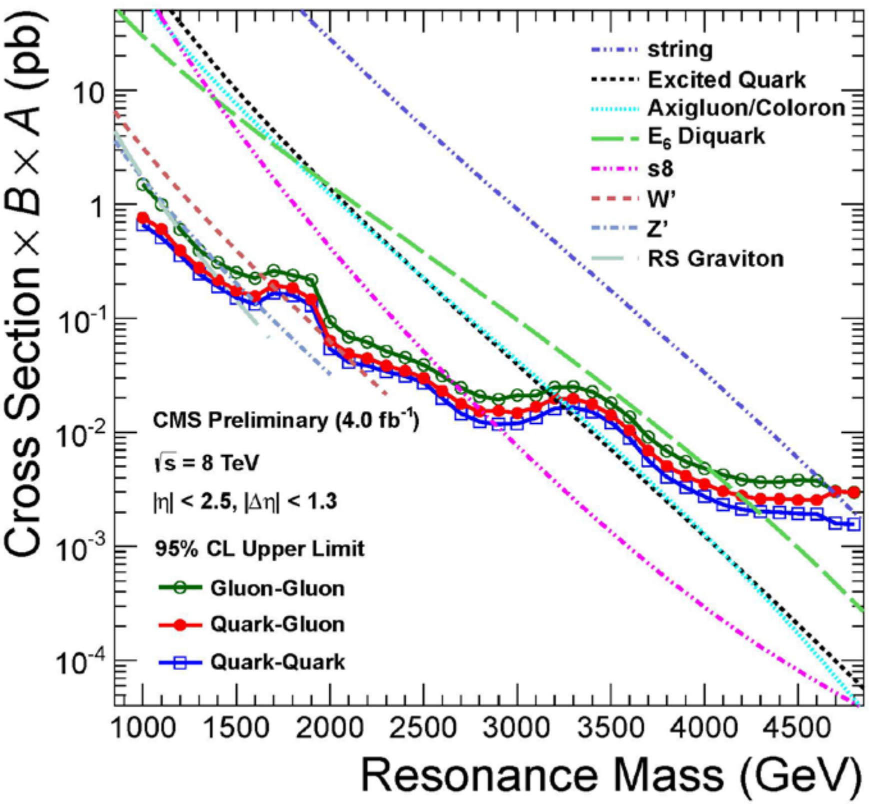
Many Zoo models can produce narrow dijet resonances..

Table 2: Summary for resonant particle names, their quantum numbers, and possible underlying models.

Particle Names (leading coupling)	J	$SU(3)_C$	$\lvert Q_e \rvert$	B	Related models
$E^{\mu}_{3,6}$ (uu)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{4}{3}$	$-\frac{2}{3}$	scalar/vector diquarks
$D^{\mu}_{3,6}$ (ud)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{1}{3}$	$-\frac{2}{3}$	scalar/vector diquarks; $\tilde{d}$
$U^{\mu}_{3,6}$ (dd)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{2}{3}$	$-\frac{2}{3}$	scalar/vector diquarks; $\tilde{u}$
$u^{*}_{3,6}$ (ug)	$\frac{1}{2}$, $\frac{3}{2}$	$\mathbf{3}$, $\mathbf{6}$	$\frac{2}{3}$	$\frac{1}{3}$	excited u; quixes; stringy
$d^{*}_{3,6}$ (dg)	$\frac{1}{2}$, $\frac{3}{2}$	$\mathbf{3}$, $\mathbf{6}$	$\frac{1}{3}$	$\frac{1}{3}$	excited d; quixes; stringy
S_8 (gg)	0	$\mathbf{8}_S$	0	0	π_{TC}, η_{TC}
T_8 (gg)	2	$\mathbf{8}_S$	0	0	stringy
V^0_8 $(u\bar{u},\ d\bar{d})$	1	$\mathbf{8}$	0	0	axigluon; g_{KK}, ρ_{TC}; coloron
$V^{\pm}_8$ $(u\bar{d})$	1	$\mathbf{8}$	1	0	$\rho^{\pm}_{TC}$; coloron

Han, Lewis & Liu

- Many models can produce a narrow resonance in the dijet spectrum …here is the latest constraint from the LHC (not available 19 months ago!   Then: 7 TeV & 35 pb^{-1} only!)



Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.0, 4.69]	[1.0,4.64]
Excited Quark (Q*)	qg	[1.0, 3.19]	[1.0,3.43]
E_6 Diquark (D)	qq	[1.0, 4.28]	[1.0,4.12]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.0, 3.28]	[1.0,3.55]
s8 Resonance (s8)	gg	[1.0, 2.66]	[1.0,2.53]
W′ Boson (W′)	$q\bar{q}$	[1.0, 1.74] [1.97, 2.12]	[1.0,1.92]
Z′ Boson (Z′)	$q\bar{q}$	[1.0, 1.60]	[1.0,1.50]
RS Graviton (RSG)	$q\bar{q}$+gg	[1.0, 1.36]	[1.0,1.20]

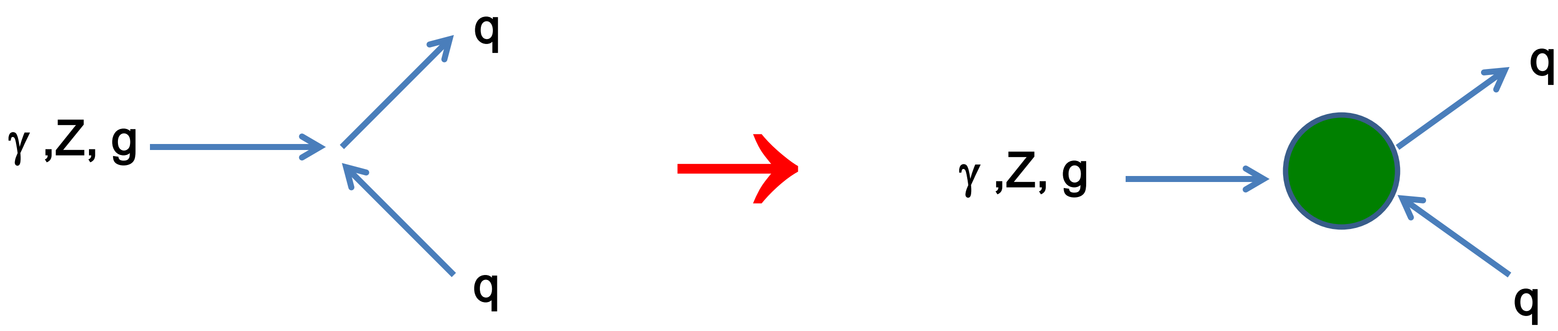
It is quite common for many Zoo members to produce similar signatures which only differ in detail

'Diagnostics' of NP once it is found will distinguish between the various models

- We can seriously degrade these constraints if the 'axigluon' is somewhat wider , i.e., $\Gamma/m > \sim 0.2\text{-}0.3$ which is easy enough to do, e.g., using the decays to scalars ✓

- If we smear out the axigluon resonance we will still modify the dijet cross section at largish M_{jj} values that will look like some sort of contact interaction below the axigluon mass

- Huh? OK we need to digress & explain this 'contact int.' thing. A CI is a NP scenario that occurs when quarks are composite objects (historically acceptable)…if axigluons or other exchanged particles are heavy enough their (effective dim-6) ints will look like CIs



$$g\,Q\,\gamma_\mu \rightarrow g\,Q\,\gamma_\mu\,F(q^2)$$

Some history: It was observed that as q^2 (~100 MeV!) was increased the ep elastic scattering interaction was modified by a form factor due to the internal structure of the proton being resolved by the photon probe.

Something similar may happen for quarks at higher scales..

$$-e\bar{\Psi}_e\gamma_\mu\Psi_e \frac{1}{q^2} e\bar{\Psi}_p\gamma^\mu\Psi_p \to -e\bar{\Psi}_e\gamma_\mu\Psi_e \frac{1}{q^2} e F(q^2)\bar{\Psi}_p\gamma^\mu\Psi_p + \dots$$

$$F(q^2) \simeq 1 + q^2/M^2 + \dots \qquad M \sim 0.7\ \text{GeV}$$

So by analogy

$$eQ_1\bar{\Psi}_1\gamma_\mu\Psi_1 \frac{1}{q^2} eQ_2\bar{\Psi}_2\gamma^\mu\Psi_2 \to eQ_1F_1(q^2)\bar{\Psi}_1\gamma_\mu\Psi_1 \frac{1}{q^2} eQ_2F_2(q^2)\bar{\Psi}_2\gamma^\mu\Psi_2$$

$$F_1\cdot F_2 \simeq 1 + q^2/M_1^2 + q^2/M_2^2 + \dots \equiv 1 + q^2/\Lambda^2 + \dots$$

$$= \mathcal{L} + \Delta\mathcal{L}$$

$$\Delta\mathcal{L} = \frac{e^2Q_1Q_2}{\Lambda^2}\underbrace{\bar{\Psi}_1\gamma_\mu\Psi_1\,\bar{\Psi}_2\gamma^\mu\Psi_2}_{} + \dots \qquad \Lambda \sim \text{TeV}$$

a 'contact interaction'

a dim-6 operator

E.g., both1 & 2 can be quarks or 1=quarks, 2=leptons

The most general possibility for q's:

$$\mathscr{L}_{qq} = (g^2/2\Lambda^{*2}) \Big[\eta_0 \bar{q}_L \gamma^\mu q_L \bar{q}_L \gamma_\mu q_L + \eta_1 \bar{q}_L \gamma^\mu \frac{\tau_a}{2} q_L \bar{q}_L \gamma_\mu \frac{\tau_a}{2} q_L + \eta_{0u} \bar{q}_L \gamma^\mu q_L \bar{u}_R \gamma_\mu u_R + \eta_{0d} \bar{q}_L \gamma^\mu q_L \bar{d}_R \gamma_\mu d_R$$

$$+ \eta_{8u} \bar{q}_L \gamma^\mu \frac{\lambda_A}{2} q_L \bar{u}_R \gamma_\mu \frac{\lambda_A}{2} u_R + \eta_{8d} \bar{q}_L \gamma^\mu \frac{\lambda_A}{2} q_L \bar{d}_R \gamma_\mu \frac{\lambda_A}{2} d_R$$

$$+ \eta_{uu} \bar{u}_R \gamma^\mu u_R \bar{u}_R \gamma_\mu u_R + \eta_{dd} \bar{d}_R \gamma^\mu d_R \bar{d}_R \gamma_\mu d_R + \eta_{ud} \bar{u}_R \gamma^\mu u_R \bar{d}_R \gamma_\mu d_R + \eta'_{ud} \bar{u}_R \gamma^\mu d_R \bar{d}_R \gamma_\mu u_R \Big]$$

$g^2/4\pi = 1$ (by convention)

More commonly

$$L_{qq} = \frac{2\pi}{\Lambda^2} \left[\eta_{LL} (\bar{q}_L \gamma^\mu q_L)(\bar{q}_L \gamma_\mu q_L) + \eta_{RR} (\bar{q}_R \gamma^\mu q_R)(\bar{q}_R \gamma_\mu q_R) + 2\eta_{RL} (\bar{q}_R \gamma^\mu q_R)(\bar{q}_L \gamma_\mu q_L) \right]$$

$$\Lambda = \Lambda^{\pm}_{LL} \text{ for } (\eta_{LL}, \eta_{RR}, \eta_{RL}) = (\pm 1, 0, 0),$$
$$\Lambda = \Lambda^{\pm}_{RR} \text{ for } (\eta_{LL}, \eta_{RR}, \eta_{RL}) = (0, \pm 1, 0),$$
$$\Lambda = \Lambda^{\pm}_{VV} \text{ for } (\eta_{LL}, \eta_{RR}, \eta_{RL}) = (\pm 1, \pm 1, \pm 1),$$
$$\Lambda = \Lambda^{\pm}_{AA} \text{ for } (\eta_{LL}, \eta_{RR}, \eta_{RL}) = (\pm 1, \pm 1, \mp 1),$$
$$\Lambda = \Lambda^{\pm}_{(V-A)} \text{ for } (\eta_{LL}, \eta_{RR}, \eta_{RL}) = (0, 0, \pm 1).$$

The LL case is the usual benchmark

- The inclusion of the 'contact interaction' term(s) distorts the shape of various SM distributions, e.g., that for M_{jj} in the case of dijets

- However, in this case we can be more clever…look at what CIs do to the LO QCD squared amplitudes

$$
\begin{aligned}
|A(uu\to uu)|^2 &= |A(dd\to dd)|^2 = |A(\bar{u}\bar{u}\to\bar{u}\bar{u})|^2 = |A(\bar{d}\bar{d}\to\bar{d}\bar{d})|^2 \\
&= \frac{4}{9}\alpha_s^2(Q^2)\left[\frac{(\hat{u}^2+\hat{s}^2)}{\hat{t}^2}+\frac{(\hat{s}^2+\hat{t}^2)}{\hat{u}^2}-\frac{2}{3}\frac{\hat{s}^2}{\hat{u}\hat{t}}\right] \\
&\quad +\frac{8}{9}\alpha_s(Q^2)\frac{\eta_0}{\Lambda^{*2}}\left[\frac{\hat{s}^2}{\hat{t}}+\frac{\hat{s}^2}{\hat{u}}\right]+\left[\frac{\eta_0}{\Lambda^{*2}}\right]^2(\hat{u}^2+\hat{t}^2+\tfrac{2}{3}\hat{s}^2)
\end{aligned}
$$

- QCD predicts cross sections highly peaked in the F- & B-directions due to massless (t,u)-channel exchanges

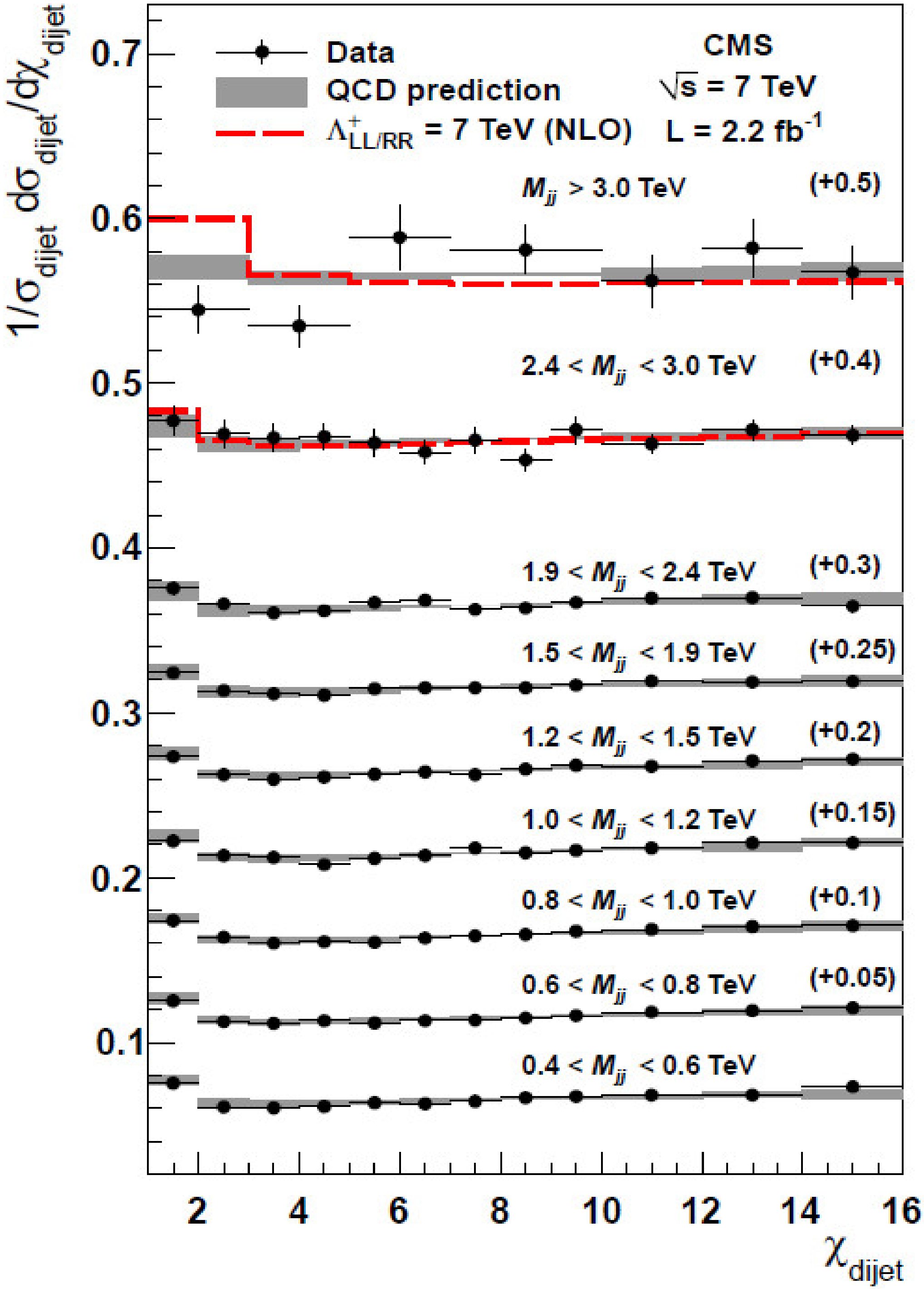
- CI terms are *not* F- or B-peaked but are rather flat in θ^* .. so consider

$$(1/\sigma_{\mathrm{dijet}})(\mathrm{d}\sigma_{\mathrm{dijet}}/\mathrm{d}\chi_{\mathrm{dijet}})$$

$$\chi_{\mathrm{dijet}} = \mathrm{e}^{|y_1 - y_2|} \qquad \chi_{\mathrm{dijet}} = (1 + |\cos\theta^*|)/(1 - |\cos\theta^*|)$$

- NLO QCD leads to essentially flat χ distributions but CIs (& other NP) will distort this shape at low χ values which correspond to large scattering angles

- Furthermore, the influence of the CI terms on σ is predicted to grows as M_{jj} is increased

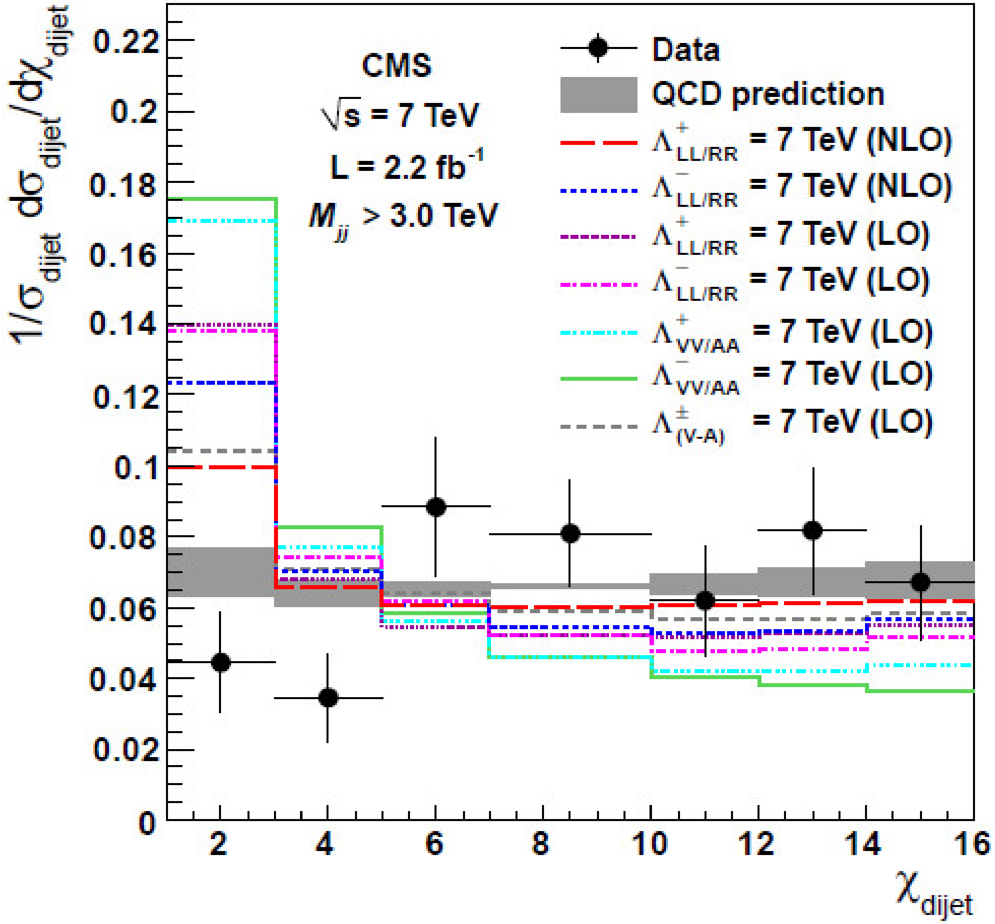


The data at low M_{jj} clearly follows the predictions of NLO QCD amazingly well as we might expect

Only in the highest mass bin do we see significant low statistics fluctuations

No obvious deviations so only limits are set

These results were far, far weaker 19 months ago!



CI model	Observed limit (TeV)	Expected limit (TeV)
NLO $\Lambda^{+}_{LL/RR}$	7.5	$7.0^{+0.4}_{-0.6}$
NLO $\Lambda^{-}_{LL/RR}$	10.5	$9.7^{+1.0}_{-1.7}$
LO $\Lambda^{+}_{LL/RR}$	8.4	$7.9^{+0.5}_{-0.7}$
LO $\Lambda^{-}_{LL/RR}$	11.7	$10.9^{+1.7}_{-2.4}$
LO $\Lambda^{+}_{VV/AA}$	10.4	$9.5^{+0.5}_{-1.0}$
LO $\Lambda^{-}_{VV/AA}$	14.5	$13.7^{+2.9}_{-2.6}$
LO $\Lambda^{\pm}_{(V-A)}$	8.0	$7.8^{+1.0}_{-1.1}$

Various CI terms can lead to different distortions in the SM cross section due to their helicity structures

Limits depend on this CI helicity structure but are all of order a few TeV

Clearly this will also constrain the exchange of heavy axigluons which we need to consider

- There are even more constraints coming from flavor physics Since the axigluon couples differently to the 3rd generation its exchange can lead to sizeable FCNC requiring M_A ~ a few TeV but are not model-independent [Glashow-Weinberg-Paschos conditions]

- Putting all this together in Jan 2011 we could actually find a region of the model parameter space that explains the value of the asymmetry and satisfy the all the various constraints !

→ Write it up & send it to the arXiv (at ~1PM PDT) : 1101.5203

SINCE then CDF has updated their data, D0 has chimed in too. Furthermore, the LHC constraints have also tightened up significantly & searched for an asymmetry as well

Now :

- This model & its variants are now excluded by the set of all data…this seems to be true for ALL of the models that have attempted to explain this observation !
- Lesson 1: In an era of rapid data accumulation new models may have very limited lifetimes
- If this observation is due to BSM physics we don't have ANY model that can explain it !
- Lesson 2: This is a very unusual situation that warrants our attention as we may need to be pushed into the unknown for an explanation

Summary

- The BSM Zoo is huge & is full of familiar, exotic & even still unknown ~~beasts~~ physics..it is landscape of all BSM theoretical ideas &models both known and still remaining to be discovered
- Thinking about the Zoo as a whole allows us to examine possibilities outside any given framework , e.g., whether or not the LHC could miss new physics & how this might happen
- The known Zoo is the starting point for the construction of new models in the advent of the discovery of BSM signals which can't be explained by existing scenarios

- An example was given as to how to modify an existing zoo member t & the steps one goes through in constructing a model to explain new data

- Hopefully at some point soon the LHC will point the way to the true model of BSM physics & we are prepared for it